Observation of W decay in 500 GeV $p + p$ collisions at RHIC

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Abstract. W boson production is observed in $\sqrt{s} = 500$ GeV proton proton collisions at RHIC-PHENIX experiment. The single longitudinal spin asymmetry $A_L(\overrightarrow{p}p \to W^+X)$ is measured via decay positrons in the mid rapidity region. The asymmetry $-0.83 \pm 0.31 \pm (11\%$ scale uncertainty) is consistent with calculations from various polarized parton distribution functions.

1. Introduction

The components of the proton spin is one of key questions in the nuclear physics. It has been proposed to use W boson production to decompose anti quark contributions [1]. In leading order process, positive (negative) W boson is connected with u and $\bar{\text{d}}$ (d and $\bar{\text{u}}$) quarks. Because of the parity violating process, it provides a unique way to access the flavor dependence of polarized quarks in the proton. It is a complementary approach to semi inclusive deep inelastic interaction experiments, where the quark flavor is identified only via the fragmentation process. In 2009, RHIC provided the first polarized proton proton collisions at $\sqrt{s} = 500$GeV. The proton polarization is achieved to be 39% for both beams.

In this article, we report the observation of W boson production and the measurement of single longitudinal spin asymmetry of W^+ production at RHIC-PHENIX.

2. RHIC-PHENIX

The data were collected by the PHENIX detector [2]. The central arm detector covers a range of $|\eta| < 0.35$ in pseudo-rapidity and 2 times $90°$ in azimuth. The primary detector for this measurement is an electromagnetic calorimeter (EMCal). Each calorimeter tower covers $\Delta\eta \times \Delta\phi \sim 0.01 \times 0.01$. A tracking system consist of a drift chamber and a pad chamber is used to identify the charge sign. Events were collected with the EMCal trigger, which is fully efficient at 12 GeV of the transverse energy. The calibration of EMCal energy scale was done with two photons' invariant mass for π^0 and η particles. For the tracking system, the detector position was calibrated with zero magnetic field data. The angular resolution of the tracking system was also checked with zero magnetic field data. Compared with the bending angle from the magnetic filed, there is 2.1 σ charge separation capability for 40 GeV/c particles. A coincidence of beam-beam counters (BBC) positioned at pseudo-rapidities $3.1 < |\eta| < 3.9$ was used as the luminosity monitor. The conversion factor from the count rate to the luminosity was obtained via the van der Meer scan technique [3], which measures the transverse profile of the beam overlap. A correction was necessary for the event overlap in a single crossing. An integrated luminosity of 8.6 pb^{-1} after a vertex cut of ± 30 cm is used in this analysis.

3. W boson signal

In this analysis, W boson is tagged by its decay electron. Electron candidates were selected from clusters in the EMCal within ±10 mrad of the transverse position projected by a charged track found in the central drift chamber. It applied loose cuts on the time measured in the EMCal and track momentum not to be much lower than the deposit energy in the EMCal. Figure 1 shows the transverse momentum spectra. The transverse momentum (p_T) is calculated from the energy deposit in the EMCal. The histogram is overlaid with curves of background (QCD events) and signal (weak boson decays). Because decay electrons from Z bosons have similar spectra to the ones from W bosons, they can not be separated in the current PHENIX detector acceptance. The main contributions from the QCD background are charged hadron clusters, photons from hadrons' decay converted to electrons before the tracking system, and some are from track mis-association in the same jet event. These backgrounds are estimated from all EMCal cluster distribution for the photon contribution and the NLO pQCD distribution folded by the EMCal response for the charged hadron contribution. First the EMCal distribution was multiplied by the probability of track association. Second the charged hadron distribution was scaled, so that the range from 10 to 20 GeV/c is explained by the sum of them. The signal shape is the decay electrons from W and Z bosons taken from PYTHIA MC smeared by the EMCal resolution. The dominant systematic uncertainty in the background estimation is from the conversion probability. It has to estimate not only for a single photon conversion, but also for a probability of two photons, because two high energy clusters from π^0 decay merge in the EMCal.

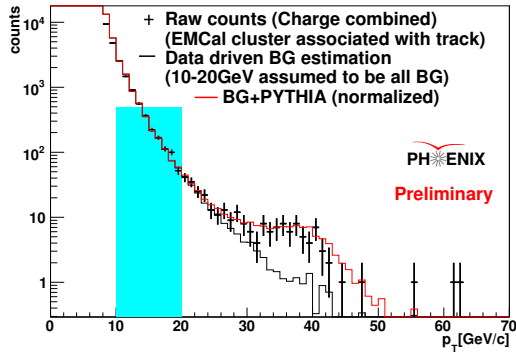A significant excess corresponding to the W boson Jacobian peak is observed in the spectra.

Figure 1. Transverse momentum spectra of EMCal clusters associated with a track in the PHENIX central arm detector. It is overlaid with curves of background and signal. The region of 10-20GeV is used for the normalization.
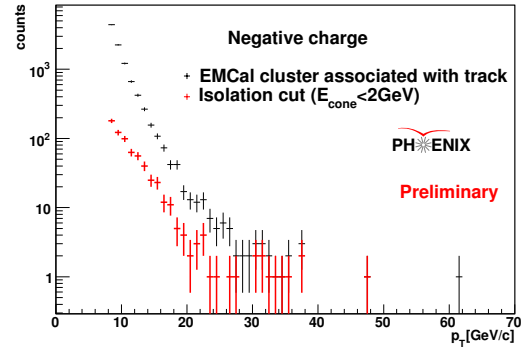
4. Single longitudinal spin asymmetry

For the spin asymmetry measurement, an isolation cut was applied to increase the signal to noise ratio. The cut is to require less than 2 GeV of energy deposit around the electron candidate. This cut should not depend on the spin state. Figure 2 and Fig. 3 show the spectra of inclusive and the one with the isolation cut for positive and negative particles. It is seen the background component from the QCD events ($p_T < 25\text{GeV}/c$) is suppressed by a factor of about 4, and the signal from W boson ($p_T > 30\text{GeV}/c$) is mostly remained. This is another evidence for the W boson signal is in the sample. The single longitudinal spin asymmetry is defined as $A_L^W = \frac{1}{P} \cdot \frac{N^+(W)-N^-(W)}{N^+(W)+N^-(W)}$, where P is the beam polarization, and $N^\pm$ is the number of signals normalized by the integrated luminosity in positive and negative helicity beam. For the luminosity measurement, number of BBC coincidence was used. Since there are two beams polarized at RHIC, the same sample can be used twice. Therefore the statistical uncertainty follows $\delta A_L = \frac{1}{P} \cdot \frac{1}{\sqrt{2(N^++N^-)}}$. In the actual calculation, the sample was divided into 4 spin states

Table 1. Single longitudinal spin asymmetry for positive particles

p_T Range [GeV/c]	Raw asymmetry
12-20 (Background)	0.035 ± 0.047
30-50 (Signal)	-0.29 ± 0.11

(2 beams × 2 spin states), then a simultaneous fit was applied to get raw asymmetries ($\equiv P \cdot A_L$). Table 1 shows the raw asymmetry of positive particles. It also shows the background region for a sanity check expecting the asymmetry to be 0. For the physics asymmetry of W bosons, it has to be corrected for the contribution of Z boson and QCD background in the sample. Those work as a dilution factor. The QCD background contribution is estimated to be 1 ± 1 event from the extrapolation of the lower part of the spectra. The ratio of Z boson to W boson is taken from PYTHIA MC ((W+Z)/W=1.08). Figure 4 shows the physics asymmetry of W^+ production after the correction. The systematic uncertainty is from the absolute polarization measurement ($\delta P/P$=9.2%) and the estimation of dilution effect ($\sim$4%). The asymmetry is consistent with predictions of various polarized PDF parametrization within the uncertainty and it is 2.7σ away from 0.
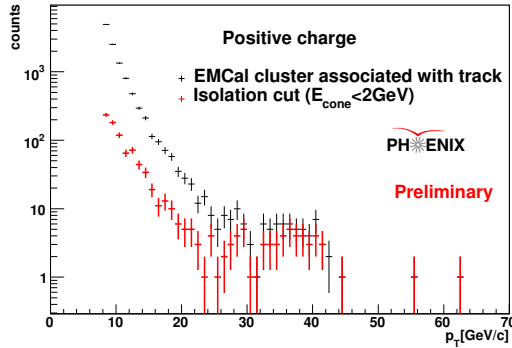
Figure 2. p_T spectra of positive particles with and without the isolation cut.

Figure 3. p_T spectra of negative particles with and without the isolation cut.

5. Summary
The W boson production is observed through its decay electrons at RHIC-PHENIX in the data collected in 2009 ($\int L = 8.6$/pb, P=39%). The single longitudinal spin asymmetry of W^+ boson is measured for the first time and it is consistent with various predictions within the uncertainty.

6. Outlook
The RHIC spin program is planning to accumulate $\sqrt{s} = 500$ GeV collision data for the next few years. There is also a plan to measure W boson to muon channel in the forward muon detectors. It has better sensitivity to the polarized $\bar{u}$ distribution than the central arm measurement because of its decay kinematics. A detector upgrade to improve the trigger capability is the major challenge in the next data taking.

The measurement of beam polarization will be an important systematics for non-zero helicity asymmetries. The systematic uncertainty has been already achieved at the level of $\sim$ 5% in the
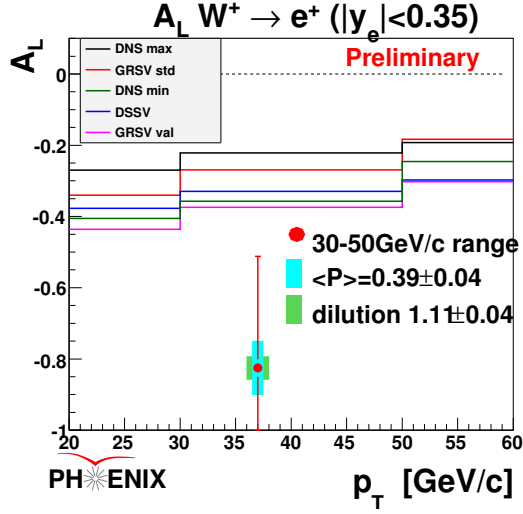
Figure 4. Longitudinal single spin asymmetry of $W^+ \to e^+$ in the mid rapidity region. It is compared with calculations from various polarized parton distribution functions. (GRSV standard, GRSV valence [4], DSSV [5], and DNS [6] using a maximal and minimal sea polarization scenario.)

absolute polarization measurement in the past 200GeV data periods. It is expected to be the same level in the next 500GeV data period.

References

[1] G. Bunce, N. Saito, J. Soffer, and W. Vogelsang, Ann. Rev. Nucl. Part. Sci. **50**, 525 (2000), hep-ph/0007218.

[2] K. Adcox et al.: Nucl. Inst. Meth. A**499**, 469 (2003).

[3] K. A. Drees and Z. Xu, "Proceedings of the PAC2001 Conference," 3120 (2001).

[4] M. Gluck, E. Reya, M. Stratmann, and W. Vogelsang, Phys. Rev. **D63**, 094005 (2001), hep-ph/0011215.

[5] D. de Florian, R. Sassot, M. Stratmann, and W. Vogelsang, Phys. Rev. Lett. **101**,072001 (2008), hep-ph/0804.0422.

[6] D. de Florian, G. A. Navarro, and R. Sassot, Phys. Rev. **D71**, 094018 (2005), hep-ph/0504155.